WLFM RADAR SIGNAL AMBIGUITY FUNCTION OPTIMALIZATION USING GENETIC ALGORITHM

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Abstract: This paper deals with optimization of ambiguity function. The purpose of article is to describe optimization process using Genetic Algorithm for suppressing side-lobes of a signal. There are also depicted properties of weighted linear frequency modulation waveform.

Keywords: Genetic Algorithm, Ambiguity function, LFM, windowing techniques

1. INTRODUCTION

Resolution, respectively radar performance, is one of the most important parameter in radiolocation. Radar performance is affected by many factors, such as wave-form, time bandwidth product, emitted energy etc. For analysis of these parameters designers use valuable tool – ambiguity function (AF). AF is two-dimensional autocorrelation function. AF represents the output of matched filter, and it describes the interference caused by the range and/or a target when compared to a reference target of equal RCS [1]. Our goal is to suppress side-lobes of AF. The reduction of side-lobes can be performed by compression of a signal and windowing techniques. Compression is realized by linear frequency modulation. In this work we use Genetic Algorithms for finding optimal envelope of signals. Results are compared with conventional windows.

2. AMBIGUITY FUNCTION

As was mentioned above, AF represents the time response of a filter matched to a given finite energy signal, when the signal is received with a delay τ and a Doppler shift υ relative to the nominal values (zeros), expected by the filter [2]. AF equation (1) is

$$|\chi(\tau,\upsilon)| = \left|\int_{-\infty}^{\infty} u(t)u^*(t+\tau)exp^{(j2\pi\upsilon t)}dt\right|, \qquad (1)$$

where u(t) is radar transmitted waveform. For our purposes, we chose linear frequency modulation LFM, which has sufficient compression ratio.

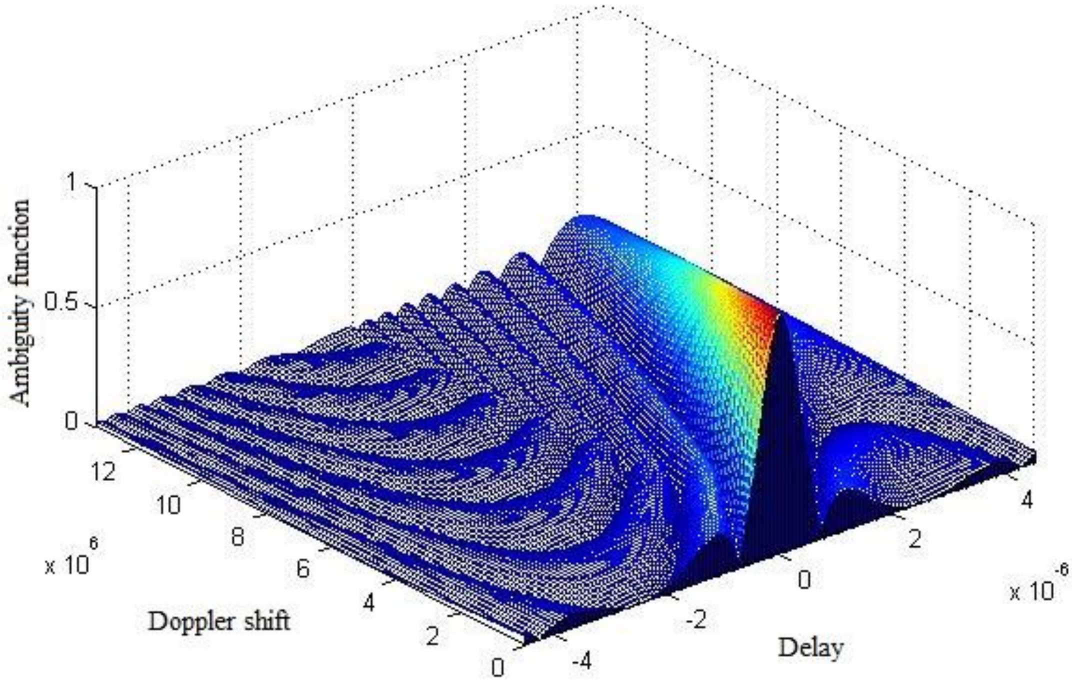

Figure 1.1: Normalized ambiguity function

The complex envelope of a LFM (2) pulse is given by

$$u(t) = \frac{1}{\sqrt{T}} rect\left(\frac{t}{T}\right) \exp(j\pi k t^2), \tag{2}$$

where k (3) is frequency rate

$$k = \pm\frac{B}{T}. \tag{3}$$

The basic idea is to sweep the frequency band B linearly during the pulse duration T [2] (Fig.1.2). In this case we displayed LFM pulse which has bandwidth 100 MHz and pulse duration 5 μs.

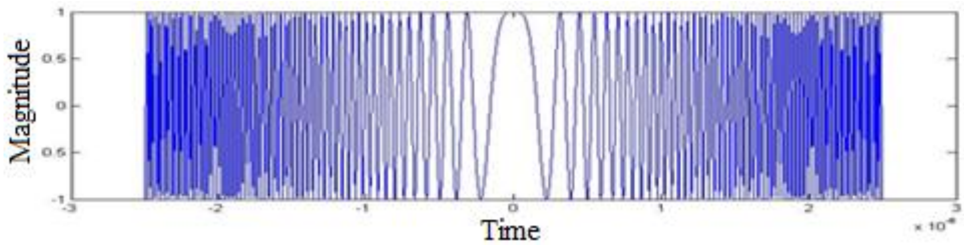

Figure 1.2: Normalized LFM pulse

3. SIDE-LOBE SUPPRESSION

As was mentioned, LFM improves the range resolution, but it has not effect on side-lobes. Relatively high side-lobes remain in the AF, respectively in the autocorrelation function (ACF). ACF side-lobes can be reduced by shaping a spectrum. Spectral shaping can be implemented by using two different approaches: amplitude weighting or frequency weighting [2].

In this paper, we focused on first approach – amplitude weighting. Windowing techniques significantly reduce side-lobes. The best known are Hamming with first side-lobe -41 dB, Hanning -32 dB and Kaiser -46dB. For comparison our current rectangular window has first side-lobe -13.46 dB. Unfortunately, these common windows have a negative impact – main beam widening. Main beam gets wider twice or more.

From the aforementioned aspects we decided to find window via Genetic Algorithm and compare it with conventional windowing techniques.

4. USING GENETIC ALGHORITHM

Genetic algorithms belong to global optimization techniques, i.e. they are able to search for most minima in a defined region. Moreover, there are no limitations to the character of the objective function. The objective function does not need being continuous, differentiable, and in the marginal case, it can be even determined by the table of empirical data [3].

GA is based on principles of biological evolution with main idea "survival of fittest" [5]. The optimization process can be simplified and divided into next few points.

1. Randomly generated population of chromosomes.
2. Every individual (chromosomes divided genes) into in the population is evaluated.
3. Elimination of the worst.
4. Pairing.
5. Crossover – create two new individuals from the chromosomes of the couple.
6. Next mutation

For our experiment we use MATLAB toolbox called Genetic Algorithms for Optimization Toolbox.

As a fitness function we have chosen integrated side lobe level (ISL), which is clearly defined as:

$$ISL = 2\sum_{k=1}^{N-1} |r(k)|^2, \tag{4}$$

where r is autocorrelation function. In our algorithm we start to find maximum value of first side-lobe of ISL. On Fig. 4.1 red line represents ISL and blue one AF. In second step, we performed minimization of the fitness function by predefined GA function in MATLAB. As was mentioned in third chapter, our optimization process estimates most convenient amplitude of signal u (t).

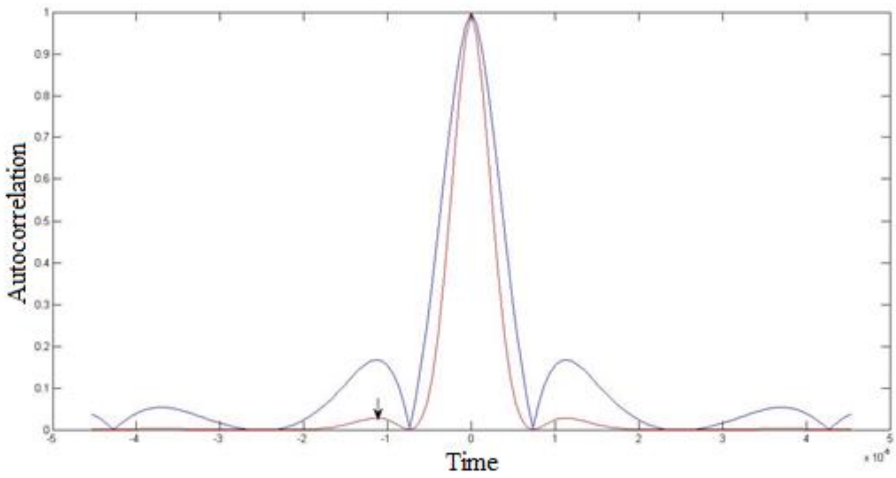

Figure 4.1: ISL and autocorrelation function

After GA processing, we get values of amplitude window (n samples). For better idea of comparison between e.g. Kaiser window (blue line) and generated values (red line) serves Fig.4.2. GA is calculated for 75 n samples, which are samples of the signal. We need to set maximum number of generations, n * 100, in order to reach compromise between the best result and CPU time. We set lower and upper bounds 0.2 and 1.2 to refine results and speed up the process. Note that results of each mutation differ.

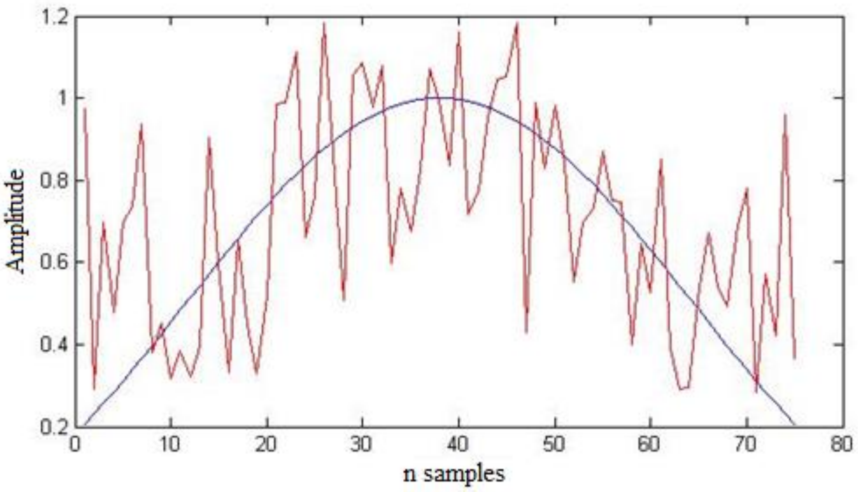

Figure 4.2: GA results and Kaiser Window

Next Figure 4.3 depicts a partial result – ACF of optimized envelope end Kaiser window. Optimized amplitude (OA) has satisfactory properties. OA (red line) main-lobe is narrower than Kaiser (blue line). Peak value of the first side-lobe of OA reaches similar values of Kaiser side-lobe, which indicates sense of this solution. The problem is to approximate the red curve on Fig.4.2. Note that parameter alpha was chosen 5. It is trade-off between side-lobe level and main-lobe width.

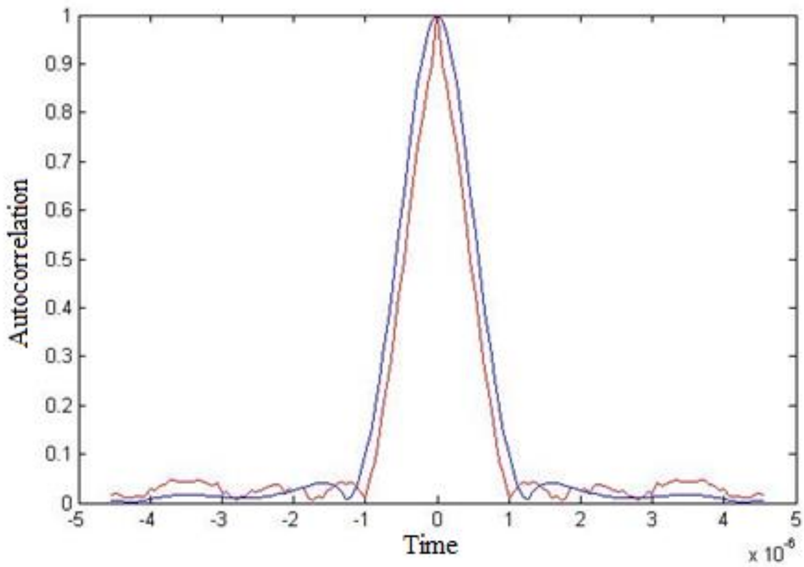

Figure 4.3: ACF of OA and Kaiser window

Final part of our problem is to implement OA into ambiguity function and it is depicted on Fig.4.4.

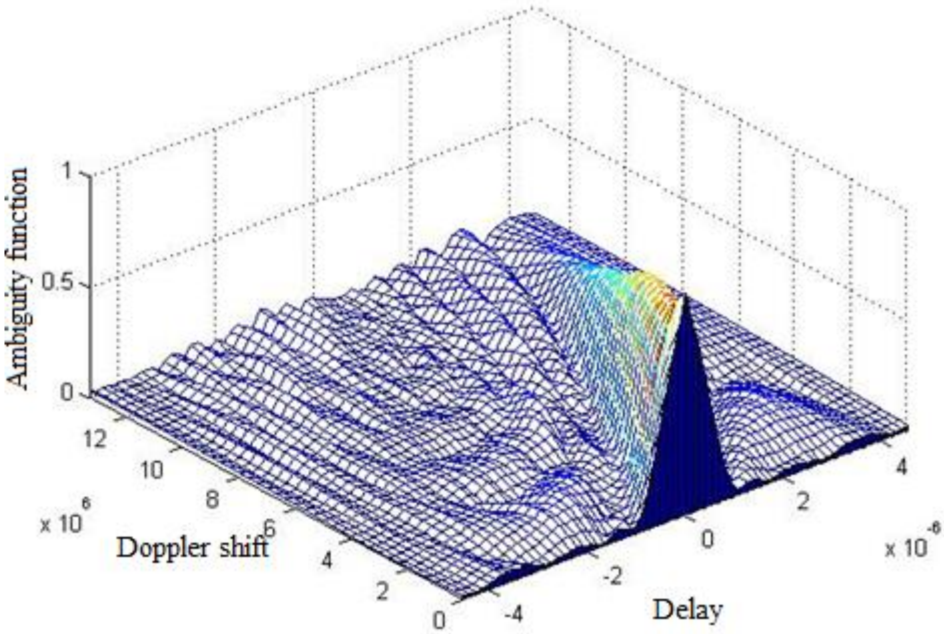

Figure 4.4: Optimized ambiguity function

On the figure are displayed two quadrants of optimized AF because of its symmetry. Optimized AF is analogical to the solution of optimized ACF with one difference – second dimension. As can be seen, the ridge of ACF, which is caused by Doppler shift, is now sharper than on fig.1. Also, Main side lobe is wider. Fig 4.5 shows one of the last opportunities for comparison – frequency domain characteristics.

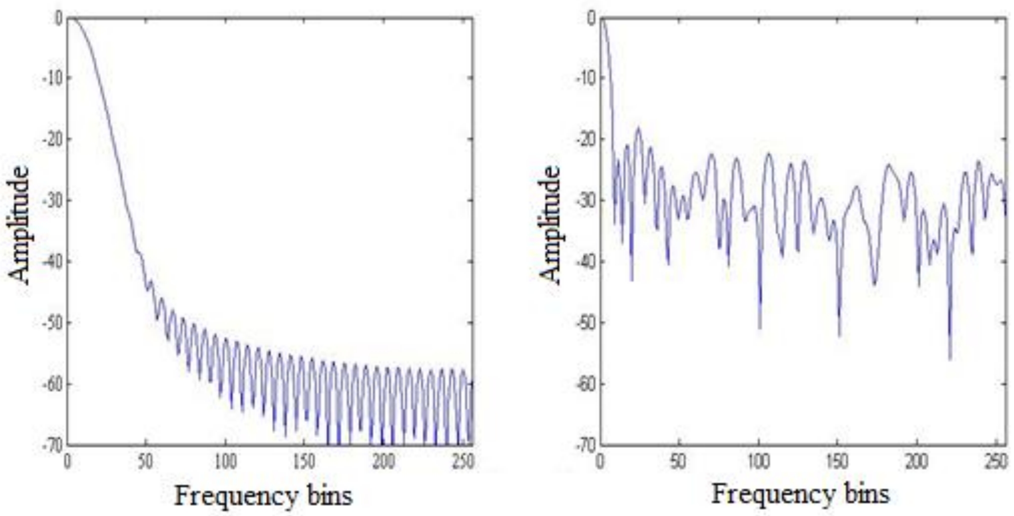

Figure 4.5: Frequency domain characteristics, left – Kaiser window, right - GA window

Similar issue was discussed in article [4]; authors proposed utilizing GA for suppressing side-lobes of quad-phase code for monostatic and multistatic radars. The results of both papers could be comparable. In conclusion, almost every signal designer exploits AF and it only depends on designer's experiences how they use AF.

5. CONCLUSION

Our results show that GA optimization can improve signal characteristics. In first chapter, there is introduced AF and waveform that we analyzed. Goal of the article, which was to suppress side-lobes in AF by Genetic algorithm, was realized. Simulation was designed in MATLAB. Our results were compared with Kaiser window technique. Plots depict process of optimization and they help to describe it. Our further work will be focus on a spectral mask, which is important for next implementation of the LFM radar waveform. A spectral mask will be used as another criterial function in GA process.

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